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Suspended microplastics during a tidal cycle in sea-surface waters around Chao Phraya River mouth, Thailand

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ABSTRACT: The study investigated the influence of tides (low and high) on composition and abundance of microplastic. Suspended microplastics (MP) were sampled in surface waters around the Chaophraya River mouth in Upper Gulf of Thailand using Neuston trawl (330-µm mesh) during tidal cycle at both tides in rainy season (August) of 2019. The abundance and types of microplastic had been analyzed. Overall, the concentration of MP during spring tide was significantly lower than the concentration during neap tide ($p < 0.01$). Suspended microplastic particle concentration ranged from 16.74 to 59.06 pieces per 100 m^3 (spring tide) and 43.26 to 126.13 pieces per 100 m^3 (neap tide). Concentration of MP found during flood tide was higher which suggested marine derived MP. Dominant samples identified under stereomicroscope were fibers and film. Using Fourier transform infrared spectrophotometry, the majority of the particles was identified as polypropylene. The effect of the tidal amplitude was an important factor determining the extent of the variations in microplastic abundance, which was stronger between the lower low tide and the higher high tide.

KEYWORDS: microplastics, Chao Phraya river mouth, tidal cycles

INTRODUCTION

Plastic debris in aquatic ecosystems has become a huge subject of concern due to the high potential of accumulation by its long degradation time [1]. It has been estimated that the lifespan of plastic can reach over centuries or even millennia, depending on the chemical composition of the material itself and the surrounding environment.

Plastic debris reaches marine ecosystems through two main sources: marine-based and terrestrial-based sources [2, 3]. Recent studies indicated that rivers transport high amount of plastic debris into marine realms [3], estimated through modeling algorithm that annually 0.5 to 2.7×10^6 tons of plastic wastes can be loaded from inland water to the seas. Regionally, the statistical analysis indicated that 223 000 plastic items (0.7 tons of plastic) were transported annually by the Rhone surface waters to the Gulf of Lion located in NW Mediterranean Sea [4] and 2172 tons of plastic were carried into the Upper Gulf of Thailand per year [5] and this is expected to increase in the coming decades [6]. Recently, microplastic contamination and their types in sand and mud beach ecosystems of Libong island in the Andaman Sea, Thailand have been reported [7].

Plastic debris in marine ecosystems is sporadically distributed due to various reasons, including the prevailing winds and ocean circulation, coastline geography, and the points of entry into the marine environment [1, 8, 9]. Overtime, plastic debris can be fragmented into smaller particles via photo-oxidative, chemical, or mechanical mechanisms. These fragments are defined by sizes into nanoplastics (less than a few micrometers), microplastics (approximately less than 5 mm), and mesoplastics [10]. Of these, microplastics are the one receiving high attention from various researchers due to their potential as a threat to marine lives. Microplastics can transport toxic metals [11–13] and persistent organic pollutants [14].

To understand the fate of plastic debris in marine ecosystems, effects of transportation are needed either via rivers or ocean currents and/or waves. Thus far, numeral studies investigated the drifting behavior of macroplastics and microplastics in the ocean circulation [15–18], nevertheless, the studies on alluvial transportation processes of plastic fragments smaller than mesoplastics are lacking far behind. Therefore, quantitative information about terrestrial derived marine microplastics is scarce, and the relative contributions of the different sources and pathways of plastics are not well published.

This study aimed to investigate the abundance and composition of suspended microplastics in the river surface during tidal cycle and different tidal periods. The study hypothesized the difference in number of suspended microplastic particles derived from land and seas, hence numbers of particles were correlated with tidal forcing to determine the alleged origin of microplastics. This study intended to provide fundamental information for elucidating the current status and distribution pattern of suspended microplastics for further study on the effects of microplastics on plankton or plankton feeders in the study area.

MATERIALS AND METHODS

Study area

The origin of the Chao Phraya River is the confluence of the Ping, Wang, Yom, and Nan rivers at Nakorn Sawan Province about 200 km north of Bangkok. The water discharges into the river were 12–500 million m^3/month in the wet season (May-November) and 0.6–11 million m^3/month in the dry season (December-April) [19]. The Chao Phraya River provides the largest riverine influx to the Gulf of Thailand with average daily 124.21 m^3/s with streamflow ranging between 0.60 m^3/s (19 million m^3/month) and 26.32 m^3/s (830 million m^3/month) and average yearly rainfall about 1127 mm (Unpublished data from Haii, 2012). The Chao Phraya River catchment area encompasses much of the central region of the country (160 000 km^2 or 30% of the area of the country) with more than 20 million inhabitants and includes many large cities as well as areas of intensive industrial and agricultural activities (Fig. 1). The Lower Chao Phraya River basin has a drainage area around 21 725 km^2 [20].

The Chao Phraya River Basin is located in the Asian monsoon region with heavy rainfalls due to influence from the South China Sea and the Bay of Bengal. Moreover, high tides in the Upper Gulf of Thailand provide strong tidal actions which cause problems of salinity intrusions, high rates of sedimentation, and high amount of discarded debris. The correlation between tides and microplastics is investigated in this study.

Hydrodynamic data gathering

The ADCP (Acoustic Doppler Current Profiler-1200 kHz Teledyne RDI Sentinel-V) was towed by a small fishing boat across the river with 600 m width. Each time two independent measurements were taken to increase the reliability of the data. ADCP was located roughly one metre below the water surface with the third beam aligned along the platform's centreline. The bin size was set to one metre. The velocity profiles were obtained from 1.5 m depth from surface to the bottom. Survey data was obtained at the cross-channel study site over two mixed tidal periods – once during spring tidal conditions on 17–18 August and again during neap tidal conditions on 24–25 August. Cross-channel ADCP surveys were made once every tidal cycle. A temporal gap during nighttime occurred because of intense maritime traffic.

Sample collection

To investigate the quantity and size distributions of small plastic fragments, field surveys were conducted at Chao Phraya River mouth in August 2019

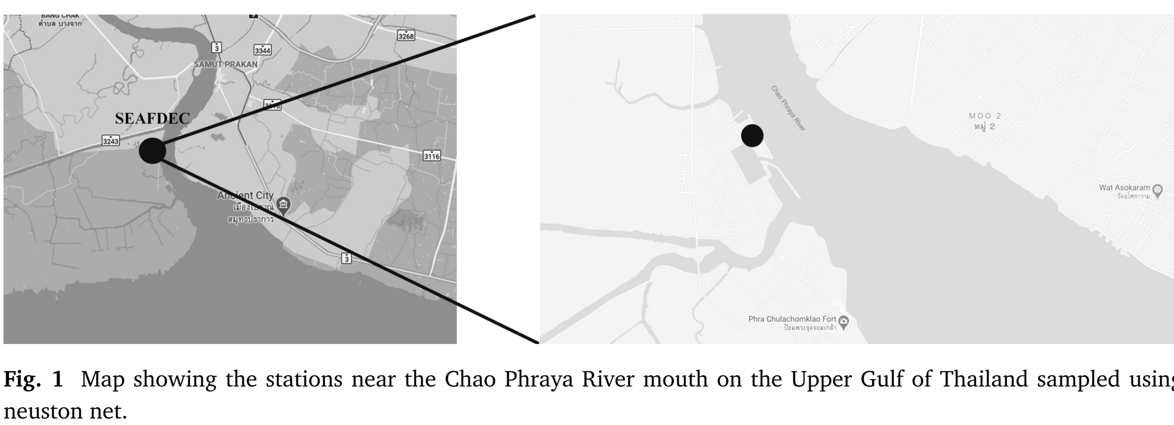

Fig. 1 Map showing the stations near the Chao Phraya River mouth on the Upper Gulf of Thailand sampled using neuston net.

during tidal cycle in spring tide and neap tide (Fig. 1 and Table S1).

A neuston net (75 cm in diameter, 300 cm in length, and 0.33 mm in mesh size), originally designed for sampling of zooplankton, fish larvae, and fish eggs near the sea surface, was used for sampling mesoplastics and microplastics [21]. A flowmeter was installed at the mouth of the neuston net to measure the water volume passing through during sampling. The neuston was deployed off the port side. The samplers were all towed at a ship's speed of 2–4 knots for 15 min in the direction of upstream river around red point as shown in Fig. 1. In total, eleven samples were collected, of which six were collected during spring tide and five were from neap tide.

Microplastic observation, extraction, and identification

Collected water samples were first fractionated into two size classes: less than 330 μm and 330 μm–2 mm. Water samples were treated solely with wet peroxide oxidation to remove organic matter [22]. Samples were then filtered with Whatman filter and 330 μm mesh filter cloth, transferred into glass petri dishes, and covered with a glass lid.

Identification of microplastics

All potential microplastic particles were subjected to visual examination by stereomicroscopy and identified by their colors and shapes [21]. All particles were visually examined with a stereomicroscope (Olympus Zeiss SZ51, Japan). The quantities within each size range were calculated to number of particles per seawater volume (particles/m^3). Polymer types of the samples collected were identified using a Fourier transform infrared spectrophotometer (FT-IR Type II; Perkin Almer, UK).

Statistical analysis

Temporal collection of microplastics from Chao Phraya River Mouth sites provided data amendable to comparison by t-test using sampling time and abundance as variables. All analyses were performed with statistical significance reported at $p = 0.01$.

RESULTS

Hydrodynamics

In the study area, hydro-geographical factors dictate the mixed tide (semidiurnal dominant) cycle. During the sampling period, tidal levels were predicted (Hydrographic Department, Royal Thai Navy). In spring tide, six samples were collected at flood tide (12:00–19:00 of 17th August, 2019) and ebb tide (06:00–16:00 of 18th August, 2019) while in neap tide, five samples were collected at ebb tide (12:00–16:00 and 22:00–06:00 of 24th and 25th August, 2019) and flood tide (16:00–22:00 and 07:00–13:00 of 24th and 25th August, 2019).

As shown in Fig. 2, the tide was mixed tide (semidiurnal dominant) with a notable spring-neap cycle. The mean depth was 3.0 m, and the range was 1.4–4.6 m. The subtidal along river mouth currents obtained using the underway ADCP data showed well-defined patterns during tidal cycle. The tidal current amplitude varied from about 0.16 to 1.2 m/s in spring tide and 0.01 to 0.57 m/s in neap tide. The strongest currents for both ebb and flood flow were observed with maximum velocities reaching 1.2 m/s there. The water quality data were collected at sampling stations as shown in Table S1.

Microplastic abundance and type

Suspended microplastic particle concentration ranged from 16.74 to 59.06 pieces per 100 m^3 (spring tide) and 43.26 to 126.13 pieces per 100 m^3 (neap tide). All collected particles were classified into two size classes: less than 330 μm and 330 μm–2 mm. The total abundance of particles sizes less than 330 μm ranged from 14.53–56.92 particles/m^3 during spring tide and 24.42–115.31 particles/m^3 during neap tide (Fig. 2a). The total abundance of particles sizes more than 330 μm were ranged from 1.34–7.33 particles/m^3 during spring tide and 1.03–22.68 particles/m^3 during neap tide (Fig. 2b). The monthly precipitation was 97.8 mm in August 2019 which fell within the range of the average annual rainfall (170 mm) in 2019 (https://www.tmd.go.th). Particle size of less than 330 μm was higher abundant than that of bigger size.

Type and composition

All samples were identified as fibers, pellets, film, rod, and asymmetrically shaped particles. In the smaller particle group (size less than 330 μm), dominant particles were film (spring tide) and fiber (neap tide) while in case of larger particle group (size between 330 μm and 2 mm), majority was film (spring tide) and pellet (neap tide) as shown in Table 1. Within the smaller particle group, there are some differences of relative abundance between samples collected during neap tide and spring tide. During spring tide, the first three types found were

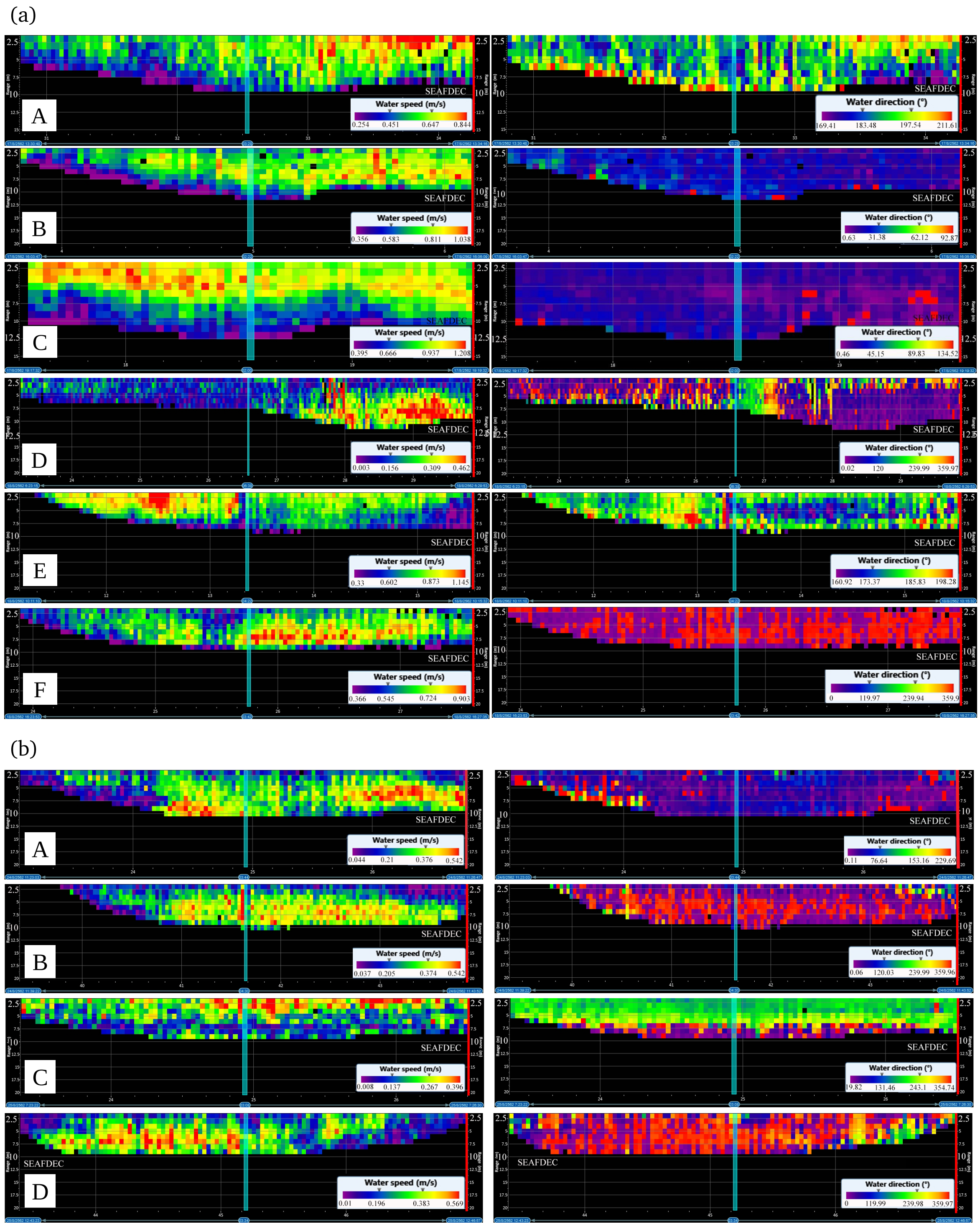

Fig. 2 (a) Color contoured current data across Chao Phraya River mouth of ADCP in some sampling times during spring tide (A) 13:30, (B) 16:00, (C) 19:00, (D) 06:30, (E) 10:00, and (F) 16:30. Right: current speed in m/s; Left: current direction in degree north. (b) Color contoured current data across Chao Phraya River mouth of ADCP in some sampling times during neap tide (A) 11:30, (B) 16:30, (C) 07:35, and (D) 12:43. Right: current speed in m/s; Left: current direction in degree north.

Table 1 Abundances (presented as mean ± SD) of suspended debris (>2 mm) in two size categories (<330 μm and 330 μm–2 mm) collected near Chao Phraya River mouth.

Type	Mean ± SD (particles/100 m^3) <330 μm			Mean ± SD (particles/100 m^3) 330 μm–2 mm		
	Spring tide	Neap tide	t-values	Spring tide	Neap tide	t-values
Fibers	6.73 ± 4.92	26.73 ± 34.8	−1.275	2.16 ± 1.65	0.73 ± 0.70	1.744
Sphere	2.60 ± 2.86	3.45 ± 5.16	−0.330	0.15 ± 0.26	3.87 ± 5.82	−1.484
Film	19.54 ± 15.93	22.91 ± 3.91	−0.506	0.72 ± 0.74	3.10 ± 4.06	−1.303
Rod	1.62 ± 1.39	0.17 ± 0.39	1.000	0.31 ± 0.48	0.08 ± 0.17	1.000
Others	0.086 ± 2.10	ND	2.242	0.1 ± 0.25	ND	1.000

ND: not detected.

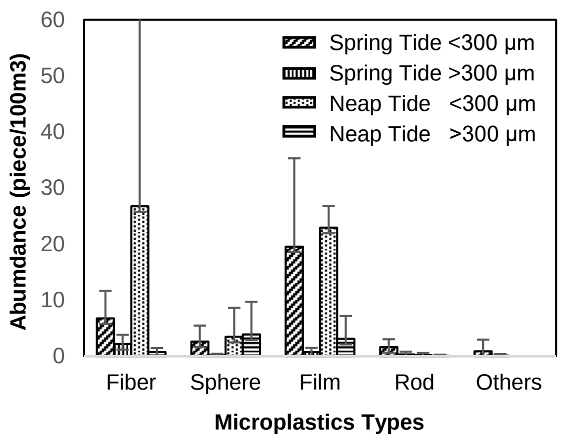

Fig. 3 Temporal variation in the average abundances of type-specific microplastics collected with neuston trawl near Chao Phraya River mouth during spring and neap tide in August 2019 (the rainy season).

film (62.35%), fibers (21.47%), and pellets (8.30%) while during neap tide, the relative abundance of fibers was the highest (50.18%), followed by film (43.01%) and pellet (6.48%). The average abundance of fibers, pellets, and film tended to increase from spring tide to neap tide (Fig. 3 and Table 1).

In the case of larger particle group, fibers were dominant (62.75%), followed by film (20.80%) and rod (9.00%) in spring tide while in neap tide, the sequence changed to pellet as the highest (49.75%), followed by film (39.86%) and fibers (9.39%). The average abundance of fibers, pellets, and film tended to decrease from spring tide to neap tide while other types of microplastics showed no clear pattern.

Fourier transform infrared (FT-IR) spectroscopy was used to compare all samples' chemical spectra with reference spectra. Microplastics were characterized as polypropylene (PP), polyethylene (PE), mix of polyethylene and polypropylene (Poly), Nylon, and Rubber. Amongst the microplastics found, polypropylene and polyethylene were prevalent and relatively dominant (Table 2 and Fig. 4). All polymer types tended to increase from spring tide to neap tide except rubber.

Table 2 Temporal variation in the abundances (mean ± SD) of type-specific microplastics collected near Chao Phraya River mouth during spring tide and neap tide in rainy season.

Type	Mean ± SD (particles/100 m^3)		
	Spring tide	Neap tide	t-values
PP	16.46 ± 4.83	37.59 ± 30.35	0.025*
PE	13.02 ± 12.30	14.60 ± 7.97	2.382
Poly	3.82 ± 3.31	4.81 ± 6.69	0.244
PET	1.38 ± 1.92	3.86 ± 7.04	0.074*
RB	0.11 ± 0.26	ND	–
NY	ND	0.17 ± 0.39	–

PP: polypropylene, PE: polyethylene, Poly: (PE+PP), PET: polyethylene terephthalate, RB: rubber, NY: nylon, ND: not detected, * $p < 0.01$.

Temporal variation

According to the tidal cycles and the microplastic abundances, time-series surveys were divided into two flood and two ebb periods in spring tide and two flood and two ebb periods in neap tide (Table S1). The average abundances of MP during spring tide (34.79 ± 16.30 particles/100 m^3) were significantly lower ($p < 0.05$) than those during neap tide (61.03 ± 36.42 particles/100 m^3) in August.

As shown in Table 3, during the flood (12:00–21:00), the amount of microplastics gradually decreased (maximum at 13:00 during the lowest low tide – LLT). This situation was due to the riverine ingress of microplastics (Fig. 5A). With the ebb (07:00–17:00), this abundance dropped considerably from the maximum at 7.00.

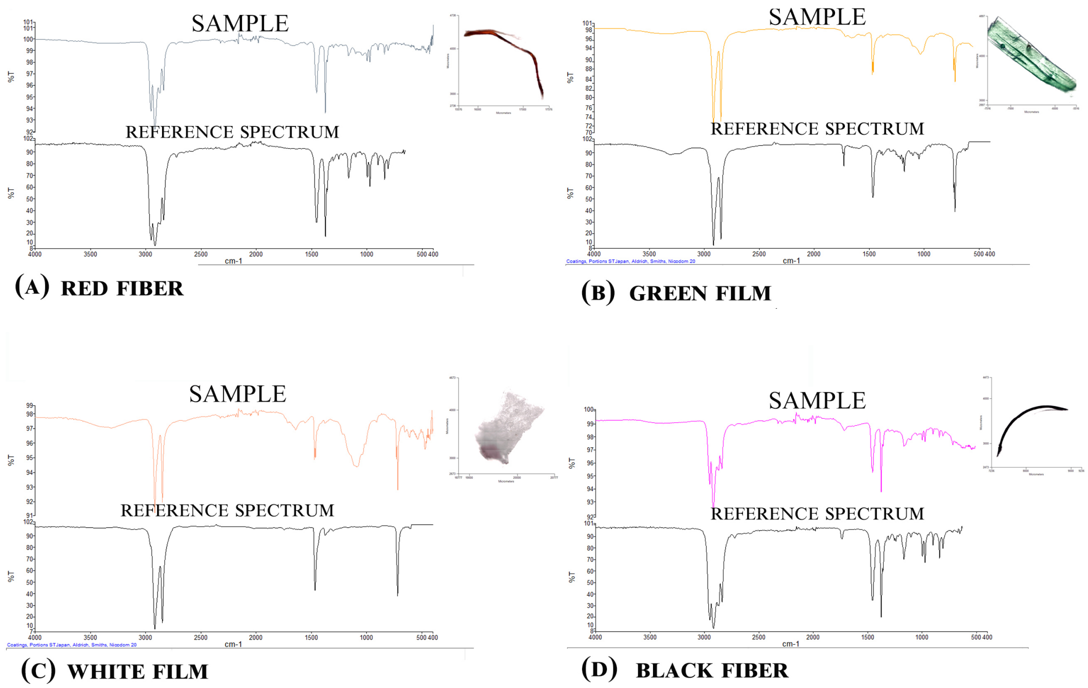

Fig. 4 Fourier transform infrared (FT-IR) spectra of microplastics and a comparison with reference spectra.

Table 3 Microplastic sampling from water at different tidal cycles. Quantity contribution from each plastic type identified is listed.

Type	Spring tide (N/100 m^3)						Particles/m^3 (mean ± SD)	t-value	t-value
	L1 13:30	T1 16:00	H1 19:00	H2 06:30	L2 10:00	T2 16:30			
PP	24.39	12.82	12.00	15.41	20.05	14.06	16.45 ± 4.81	5.32*	
PE	22.25	7.02	3.16	33.81	4.35	7.53	13.02 ± 12.30	1.40	
Poly	3.85	3.36	0.63	8.56	0.00	6.53	3.82 ± 3.31	−1.61	4.32*
PET	0.00	5.19	0.32	1.28	1.00	0.50	1.38 ± 1.92	5.89*	
RB	0.00	0.00	0.63	0.00	0.00	0.00	0.11 ± 0.26	56.14*	
NY	0.00	0.00	0.00	0.00	0.00	0.00	ND	ND	
Type	Neap tide (N/100 m^3)						Particles/m^3 (mean ± SD)	t-value	t-value
	H1 11:00	L1 16:00	H2 22:00	L2 07:00	T1 12:00				
PP	30.01	27.04	91.16	16.98	22.76		37.59 ± 30.35	2.42	
PE	11.69	2.62	15.40	22.64	20.65		14.60 ± 7.97	2.70	
Poly	1.56	16.57	3.33	2.57	0.00		4.81 ± 6.69	−0.07	3.44**
PET	0.00	0.00	16.23	3.09	0.00		3.86 ± 7.04	−0.36	
RB	0.00	0.00	0.00	0.00	0.00		ND	ND	
NY	0.00	0.87	0.00	0.00	0.00		0.17 ± 0.39	27.74*	

PP: polypropylene, PE: polyethylene, Poly: (PE+PP), PET: polyethylene terephthalate, RB: rubber, NY: nylon, ND: not detected, * significant different both $p < 0.01$ and $p < 0.05$, ** significant different only $p < 0.01$.

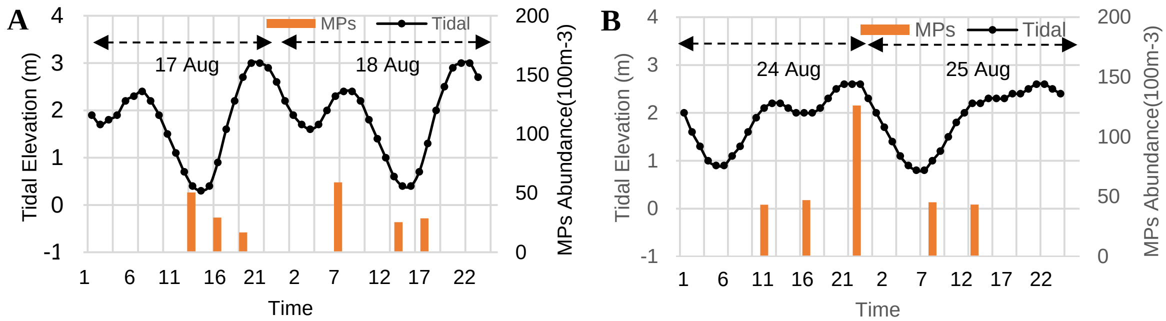

Fig. 5 Temporal variation of the surface of microplastics (MP) per 100 m^3 during tidal cycle: (A) spring tide and (B) neap tide.

MP abundance in the river was highly fluctuated temporally. Quantities of MP were compared during the first high tide period (H1), the first transition period (T1), the first low tide period (L1), the second high tide period (H2), the second transition period (T2), and the second low tide period (L2).

In neap tide, during the first ebb (11:00–16:00) and the first flood (16:00–22:00), the amount of microplastics gradually increased and reached the maximum at 22:00 (Highest High Tide) as shown in Fig. 5B. After that, the number continually decreased during the second ebb and flood tides. MP concentrations were higher during neap tide with the maximum abundance of 43.26 particles/100 m^3 of water at H1 and minimum abundance of 126.13 particles/100 m^3 of water at H2 (Table 3). MP concentrations ranged from 16.74 particles/100 m^3 of water at H1 to 59.06 particles/100 m^3 of water at H2 during spring tide.

There was statistical difference between quantities of microplastic particles found temporally during spring tide (t-test; $t = 4.32$, $p < 0.05$). Relatively, the most abundance of microplastic particles were found during H2 followed by L1, T2, T1, L2, and H1, respectively.

Quantities of microplastic particles found during spring tide also temporally varied (t-test; $t = 3.44$, $p < 0.01$). Relatively, the most abundance of microplastic particles were found during H2 followed by L1, L2, T1, and H1, respectively.

DISCUSSION

Previously, many researches were conducted on behavior and factors influencing MPs abundance and distribution in rivers such as population density, urban activities, industrial activities releasing sewage/wastewater, and dam [9, 23–26]. Of these, river system is complex and also being recognized as important pathway to distribute MP from terrestrial to oceans [6, 18, 27]. Moreover, there are also many factors (hydrodynamic flow and material characteristics such as buoyancy behavior and degradation) which control the distribution of microplastics in river [28]. While there were few studies focused on river induction microplastics, problems of process understanding, knowledge gap identifying and small size particle sampling still remained [24, 29]. Therefore, flux of MPs from river to sea is crucial.

While the abundance of debris is probably related to the proximity to the mouth of Chao Phraya River flowing through the densely populated industrial and urban areas, the average abundances of floating debris reported here are relatively lower than those in other studies. The abundance of microplastic debris found in our study area was relatively low when compared to Nakdong River in the Southeastern Sea of Korea using a Manta trawl (330-µm mesh): 0.64–860 particles/m^3 after the rainy season (July) in 2012 [30], Po River, Northern Italy: 1–84 particles/m^3 [18]. The discrepancy might be related to the data comparing inconsistency, and/or different methodologies of collecting devices and mesh sizes.

The smaller size groups of microplastics are found higher in every sampling time. Though anecdotal observation of sampling method raise some concerns, it should be noted that clogging of sampling device has been detected which can result in significant loss of microplastic quantities [30].

The frequency and number of microplastic detection are found around the globe. Thus, the importance of the evaluation of the presence of microplastics and identifying their origin is a critical point. The collected plastic particles were categorized into fiber (74%), film (17%), and fragments (9%) in this study which is contrasted with other studies elsewhere [31–34]. The source of all our particles was the breaking down of larger items, and no primary microplastics (pellets or granules) were found. The proportion of different polymers found in this study roughly corresponds to the global production stocks of plastic materials with polyolefin accounting for the majority of the global plastic demand. The six diverse polymers identified in this study are used in a wide range of domestic and marine applications, including packaging and textiles, which indicates diverse sources. Polypropylene, polyethylene, and PET were the most commonly found in this study area for both particle sizes.

Polypropylene, which is made from the combination of propylene monomers, is one of the most popular thermoplastic materials and has a wide variety of applications: food storage containers, automotive industry, and many others. Polyethylene is made for grocery bags, shampoo bottles, children's toys, and even bullet proof vests. PET is used in containers for food and beverages and fibers for clothing. Nylon is a common polymer used for making ropes, fishing lines, and draperies, etc.

Microplastics found in this study show no clear pattern whether there are originated from marine-based sources or terrestrial-based sources. However, the presence of microplastics seems to follow the influential of tidal forcing. MP tends to increase during neap tide period. Moreover, the tidal amplitude is closely related to the microplastic abundance; the stronger tidal amplitude during spring tide determines more marked temporal difference while the weaker tidal amplitude of the survey relates to a longer residence time of water masses of different origins, which delays their mixing and transport. This finding confirms the study at Changjiang (Yangtze) Estuary [35] which reported that distributions and fluxes of heavy metals and suspended matters were distinctive during a tidal cycle. Households in Bangkok city produced 872×10^6 m^3/year of domestic wastewater [36]. In addition, tidal cycle influenced nutrient status and phytoplankton composition of estuary. The nutrient concentrations were stronger between the lower low tide and the higher high tide [37, 38]. The results confirmed the influence of spring/neap tidal cycle on the difference of microplastic abundances. Tidal currents were higher during spring tide which led to high mixing water column whereas during neap tides, the decline in the intensity of tidal mixing resulted in a stratification of the water column (Fig. 2). Moreover, during neap tide (five-time sampling), all tide levels are higher than those of spring tide (except two times at 17th night and 18th morning) (Fig. 4). This high level of tide during neap tide might be due to the intrusion of seawater which also caused the tranquil of ambient water at sampling station. The tranquil of water was correlated with high abundance of microplastics collected which might be possible to conclude that source of microplastics in this study area might be originated from the river runoff. However, for estuarine ecosystem, tidal variations are the major factor affecting the water movement. This study, therefore, suggests the high-resolution monitoring programs to capture the effect of tidal variability on microplastics in estuaries should be done to confirm the finding.

CONCLUSION

This study gives a first insight of microplastic pollution sink-source in the Chao Phraya River water. It provides information on plastic particle pollution in the Chao Phraya River basin. The results show that microplastic distribution is different temporally, and films and fibers are the numerically dominant shape types of particles. Identification through FT-IR spectroscopy evidences the presence of six polymers with propylene, polyethylene, poly, PET, nylon, and rubber as the most common. The knowledge of plastic particle pollution in the surface water is extremely limited due to the high cost and safety involved with sampling around the river mouth area.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.2306/scienceasia1513-1874.2020.091.

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Appendix A. Supplementary data

Table S1 Water quality data near Chao Phraya River mouth.

Tidal level	Time	Salinity (g/l)	Conductivity (μS/cm)	TDS (mg/l)	Temperature (°C)	DO (mg/l)
Spring tide						
L1	13:30	2.19	4606	2535	30.5	4.81
T1	16:00	1.37	2955	1745	30.3	5.15
H1	19:00	2.98	6144	3310	30.5	4.07
H2	6:30	2.86	5915	4370	30.3	5.41
L2	10:00	2.06	4367	3405	30.7	4.31
T2	16:30	1.34	2879	1695	30.4	4.22
Neap tide						
H1	11:00	0.70	1560	920	30.3	4.02
L1	16:00	1.08	2359	1390	30.4	3.89
H2	22:00	1.41	3022	1780	30.5	3.47
L2	7:00	0.64	1414	840	30.2	4.12
T1	12:00	0.50	1122	660	30.2	4.61

L1, L2 = low tide; T1, T2 = flood tide; H1, H2 = high tide; TDS = total dissolved solids; DO = dissolved oxygen.